NASA's WIRELESS AUGMENTED REALITY PROTOTYPE (WARP)

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Abstract

The objective of Wireless Augmented Reality Prototype (WARP) effort is to develop and integrate advanced technologies for real-time personal display of information relevant to the health and safety of space station/shuttle personnel. The WARP effort will develop and demonstrate technologies that will ultimately be incorporated into operational Space Station systems and that have potential earth applications such as aircraft pilot alertness monitoring and in various medical and consumer environments where augmented reality is required. To this end a two phase effort is being undertaken to rapidly develop a prototype (Phase I) and an advanced prototype (Phase II) to demonstrate the following key technology features that could be applied to astronaut internal vehicle activity (IVA) and potentially external vehicle activity (EVA) as well: 1) mobile visualization, and 2) distributed information system access. Specifically, Phase I will integrate a low power, miniature wireless communication link and a commercial biosensor with a head mounted display. The Phase I design will emphasize the development of a relatively small, lightweight, and unobtrusive body worn prototype system. Phase II will put increased effort on miniaturization, power consumption reduction, increased throughput, higher resolution, and "wire removal" of the subsystems developed in Phase I.

INTRODUCTION

The Wireless Augmented Reality Prototype was conceived in late 1996 as part of NASA's Office of Life and Microgravity Sciences and Applications (OLMSA) ongoing effort to develop technology capabilities to support humanities quest to use and explore space. Initiated in January 1997, WARP is a means to leverage recent advances in communication, display, imaging sensor, biosensor, voice recognition, and microelectronic technologies to develop a prototype system capable of real-time personal display of information relevant to the health and safety of Space Station personnel. The original concept for the system is depicted in Figure 1.

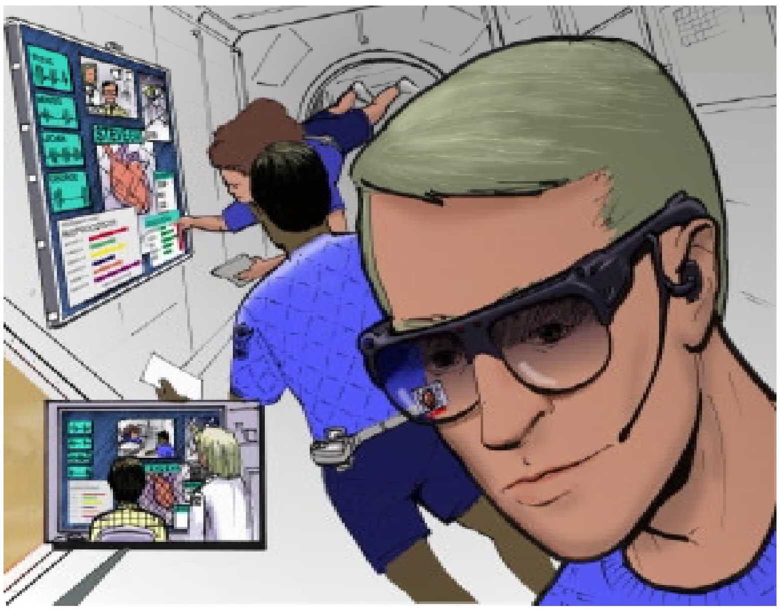

FIGURE 1. Original WARP Concept.

WARP will allow an unteathered astronaut floating in the Space Station, wearing a lightweight head mounted display (HMD) and outfitted with a suite of miniature biosensors to communicate through a two way wireless communications link to the Space Station communication infrastructure. On the miniature head mounted display (HMD) the astronaut will be able to view his or the other astronauts' biosensor data (e.g., heart rate or oxygen saturation), imagery (e.g., wiring diagrams), or text transmitted from the Space Station or Mission Control on earth. A miniature camera worn on the astronaut will allow the viewing of his environment back on earth (e.g., a patient being administered to), and real-time video teleconferencing. Control of these various capabilities will be via voice commands and speech recognition software thus allowing hands free operation.

The Jet Propulsion Laboratory (JPL) is working in conjunction with its partners at the University of California at Los Angeles (UCLA), and McDonnell Douglas Aerospace in the development of WARP. An initial prototype including a subset of the ultimate capabilities will be completed within one year to demonstrate the concept and technologies. This prototype is to be followed by a refined prototype with additional capabilities, reduced size and power requirements (resulting in smaller batteries), and incorporating emerging technologies.

SYSTEMS ARCHITECTURE

In defining the system architecture, several approaches were investigated that could lead to a Phase I demonstration system sooner than the planned twelve month effort, while at the same time provide sufficient capability for a representative demonstration, and lead naturally into an advanced Phase II system. The requirements for this demonstration system are listed in Table 1 and a conceptual drawing is shown in Figure 2. The initial WARP system architecture will provide for transmission of compressed video and audio from the base station to the astronaut. At the same time it will allow compressed audio and biosensor data to be transmitted from the astronaut to the base station. The transmission of video will allow the head mounted display on the astronaut to present the required biosensor plots as well as other basic PC functions operating at the base station, all via voice control. Essentially the astronaut will be controlling a PC at the base station remotely via the voice link with the display remoted to his local head mounted display. This allows the astronaut to make use of the computational, storage, and connectivity capabilities available at the base station.

TABLE 1. Requirements for Demonstration System.

High Level Requirements
- build ASAP in order to demonstrate technologies and their capabilities
- miniature head mounted display (HMD) on IVA astronaut
- commercial biosensor data transmitted from IVA to base station
- voice link to/from IVA astronaut
- voice control of HMD display
- HMD must display biodata, imagery (graphics & text)
- must operate reliably in space station "metal box" environment
- must operate reliably while IVA astronaut is moving about space station
- size, weight, and power (battery powered) must be minimized on the IVA astronaut
Derived Requirements
- transmit compressed video of base station PC VGA display (bio-data/graphics/text) to IVA astronaut HMD
- communications link maximum range = 10 meters
- camera on IVA will be incorporated in Phase II

In an effort to build the WARP demonstration system rapidly, commercial-off-the-shelf (COTS) hardware and software are being utilized to the extent possible. The base station utilizes an industrial passive backplane PC equipped with commercial boards and voice recognition software. The communication link requires some development for the demonstration system, but to the extent possible commercial based chip sets are being utilized in the design. The video/audio compression is based on a standards based compression product. The biosensor is being selected in collaboration with the NASA Ames Advanced Sensor Systems group and will be a commercially available device. The head mounted display is a new design by the industry leading manufacturer of small lightweight HMD's which concentrates on wearability. Integration of all these technologies into a fully functional reliable system is one of the key challenges of WARP.

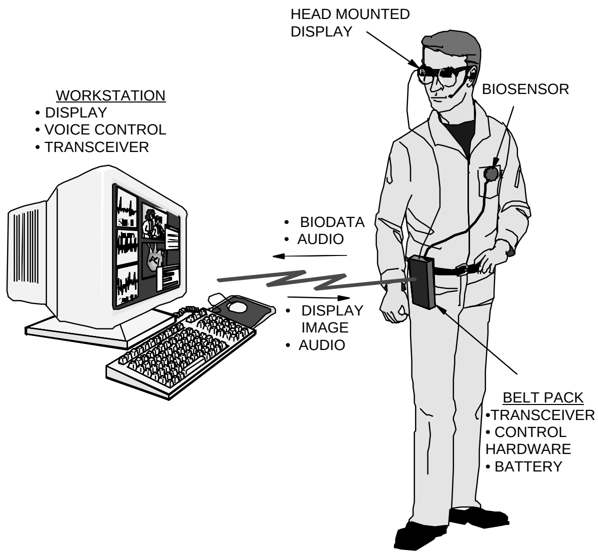

FIGURE 2. Demonstration System Concept.

Based on the basic system architecture a series of demonstrations have been devised that will allow the rapid validation of the system concept and an incremental building up of capabilities and improved functionality while experimenting and adding/eliminating options in order to optimize the system configuration. These demonstration systems are briefly discussed below.

Demo A

The first demonstration consisted of entirely commercial off-the-shelf (COTS) belt-worn PC/HMD system running a software audio/video codec on the CPU. The belt-worn PC system has a wireless LAN connection to the base station PC. This 100% commercially available system allowed us to evaluate a partial WARP capability implemented in a miniature commercial PC and at the same time provide a limited operational demonstration in the short term. This demonstration showed the limitations of software codecs (e.g., low resolution, not motion friendly, require full processor), and the bulkiness of current HMD's.

Demo B

The second demonstration was intended to be more representative of the ultimate WARP system in that it integrated a hardware audio/video codec together with a breadboard version of the primary miniature communication system candidate. Additionally, the base station computer was configured with a voice recognition operating system controlled via the wireless link. This demonstration, while quite large (e.g., rack mounted codecs) evaluated the feasibility of the video codec based approach. The throughput performance and reliability of the communication system was tested (and determined that improvements are needed), and the voice recognition software was shown to operate over a compressed audio link.

Demo C

Currently in the process of being fully specified, this demonstration system will have a size on the order of a sub-laptop computer and most of the desired WARP functionality shown in the Figure 3 block diagram, but will not be fully customized to minimize power and size. Additionally, Demo C will have the capably to transmit compressed video both to and from the IVA astronaut, enabling full-duplex video teleconferencing.

Demo D

This demonstration, being developed concurrently with Demo C, will result in a miniaturized belt worn version of the system shown in Figure 3. It will have improved communication system performance and improved video image quality. Demo D is the early initiation of the Phase II system.

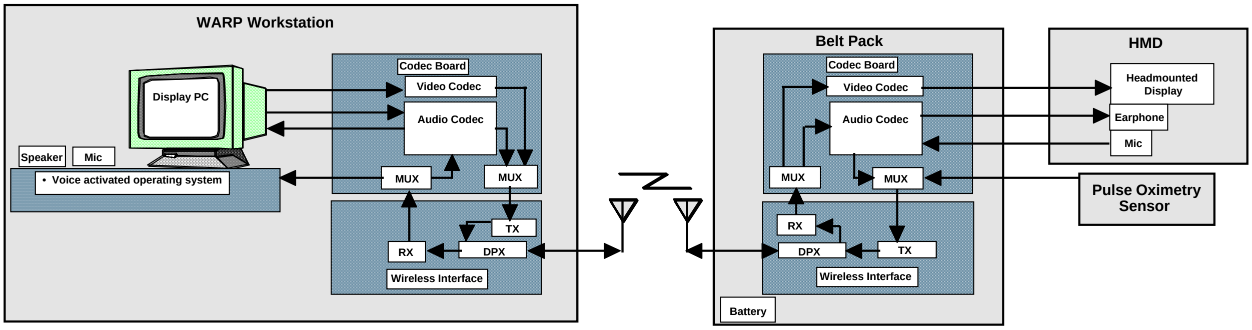

FIGURE 3. Demonstration System Block Diagram.

COMMUNICATION SYSTEM

One of the greatest challenges in developing the WARP is designing a wireless system for indoor communications that will perform reliably in the harsh environment of the Space Station. The first priority was to verify that in fact it is possible to communicate inside a "metal box" that resembles the space station environment. Through extensive testing of the communications system in a metal trailer “space station simulator” such a connection has been proven and the results of these tests have been incorporated into the design of the demonstration system. The Space Station radio frequency communication channel is equivalent to operating within a large metal box, which has the effect of the transmitted signal reflecting off of the metal surfaces and arriving at the receiver with different delays, thus creating destructive self interference. Methods of counteracting this interference that are realizable in a small, low power implementation are being investigated.

A communication system designed to operate in the high multipath space station environment must necessarily utilize a non-coherent demodulation scheme because of the difficulty of tracking the phase in this environment. At the present time, Differential Phase Shifted Keying (DPSK) and Frequency Shift Keying (FSK) have been tested as the candidate techniques for modulation. Spread spectrum, antenna diversity and retransmission techniques are also being investigated as means of improving the reliability of the communications link. Through a combination of these techniques, channel throughputs greater than 384 kbps can be achieved. A variety of RF frequencies have been tested, but the determining factor in frequency band selection will be the availability in that band of a relatively large amount of spectrum in the space station, allowing the transmission of compressed video. Currently, the 2.5 to 2.7 GHz band is a prime candidate, due to good chances of receiving certification for use and the potentially low amount of interference it will sustain.

The needs for WARP project team to build a miniature communication system in a relatively short period of time will necessitates leveraging heavily off of the currently available wireless LAN. Looking toward the future, the greatest potential for improvement and innovation is in the arena of higher-bandwidth communications which would allow higher quality video to be transmitted to and from the astronaut. Using commercial components soon available, the next level WARP should achieve data rates approaching 1 Mbps in the space station environment. For far-term improvements, a collaboration has been initiated with UCLA in which communication system designs that can reliably achieve 10+ Mbps data rates in the space station are being investigated.

Preliminary Communication System Tests

Extensive one-way testing of breadboard 280 MHz and 2.4 GHz radio systems has been done both in the laboratory environment as well as a simulated Space Station module, which consists of a 40 foot fully enclosed metal trailer with various metallic obstructions. The basis for this breadboard system was the Harris Prism wireless LAN chip-set together with simple monopole antennas optimized for 280 MHz and 2.4 GHz, respectively. This chip set allows communication at either differential BPSK or QPSK and implements a pseudo-noise (PN) code spread-spectrum radio capable of data rates up to 2 Mbps. The Prism system does not provide explicit multipath compensation; however, the chip set does have the capability to support antenna diversity, and can support receive-acknowledge protocols for data retransmission.

Another chip set, by Broadcom Corp., was used in initial testing because of the potential it offered for achieving multiple megabit/sec data rates. Unlike the Prism, this system allows for adaptive equalization within the digital functions of the baseband processor. This system did not perform well in the space station simulation, however. It is likely that the equalization technique used, developed specifically for the fairly benign conditions of a cable modem communications channel could not adjust rapidly enough to the dynamic conditions of the simulator with moving human occupants.

During testing, the frequency-selective effects of signal scattering in the simulator trailer could be easily observed by looking at the received signal on a spectrum analyzer. The received spread signal exhibited varying numbers of 5-10 MHz bands which would dynamically peak and fade versus the overall pattern. The pattern of the bands would change drastically from even small motions of people in the simulator, illustrating the large impact of having mobile RF absorbers/reflectors (i.e., people) in the otherwise static environment.

The simulator test setup used a bit error rate tester (BERT) to produce simulated data at the transmit end and to display channel characteristics at the receive end, including individual bit errors detected. During a typical test, the receiver portion of the set-up (representing the astronaut) would be moved around in the simulator. It was possible to spatially locate areas where maximum interference was occurring by finding locations that produced the greatest amount of errors.

Various configurations were tested, including: low (72 kbps) through high (1 Mbps) rate data, different transmit power levels, QPSK vs BPSK, and different spatial distributions of obstacles and human observers. In all configurations it was possible to arrange the two ends of the test set up such that error-free performance could be achieved over the course of hours. The distinguishing performance criteria between configurations were strictly the number, size, and depth of peak interference locations which could be found in three dimension space. With the best configurations, finding locations to produce any errors at all could be extremely difficult, and not repeatable. In poorly performing configurations, it was easy to find areas which could continuously produce errors.

Clearly, BER performance of the tests were hard to quantify. Depending on location of the transmitter and receiver, the test set up could perform at better than 10^{-8} or worse than 10^{-4}. The BER experienced in a real-world situation would obviously be some average of the error rates achievable over all the spatial locations traversed by the astronaut. Reducing the number and physical size of the interference regions by choice of radio design would make it more likely that the astronaut belt-pack receiver would only cross a fading area momentarily before moving back into a clear zone.

The main result of the testing was that by far the most significant factor in reducing the number and size of interference locations was data rate. For example, one test compared the benefit of reducing the power amplifier output by 27 dB (@280 MHz) with the performance improvement obtained by reducing the data rate from 575 Kbps to 287 Kbps, an E_b/N_o difference of about 3 dB. Reducing the transmitter power output had little impact on the system performance. Reducing the data rate by half, however, produced an obvious improvement, going from a reasonably stable system with some interference points to a link in which almost no errors could be induced. The primary reason for such behavior is that when the data rate is reduced the bit period is lengthened and as a result the RMS delay spread of the received multipath signal becomes a smaller fraction of the bit period resulting in less inter-symbol interference.

HEAD MOUNTED DISPLAY

The design of the head mounted display (HMD) began with the artist's concept image of a display and functional requirements. One of these requirements is that the HMD be wearable for the performance of "normal" duties and for extended periods of time. For the headset, it was determined that COTS designs could not provide the wearability and functionality that WARP requires. After an extensive industry survey a manufacturer was chosen that could provide rapid prototyping and in-house design and fabrication. The design leverages heavily off the optics and circuitry designed into products produced for other government agencies and industry.

Efforts focused on producing the most lightweight and wearable HMD possible and resulted in the design shown in Figure 4. The HMD will provide its wearer with video display, stereo audio, and a noise canceling microphone. Accommodation has also been made to allow for the addition of a miniature video camera for future integration as communications bandwidth is available. The headset will weigh less than 3.5 ounces when completed, which is approximately 10 ounces less than similarly equipped "state of the industry" headsets. The Phase I headset will provide NTSC video through a single bounce optical prism.

FIGURE 4. Mockup of Phase I Demo Head Mounted Display.

The HMD can be worn over prescription eyewear and with bi-focal prescription eyewear. The optic can be "flipped-up" out of the line of sight and the video display will go into "sleep" mode to conserve power until it is brought back down into the field of view; the audio and bio-sensor systems continue operating during "sleep" mode. This headset will not block peripheral vision which is an advantage for a device that is to be worn consistently. The headset also can be adjusted and "formed" to the individual's head shape as needed. Furthermore, the optic and display circuitry can be positioned for either right or left eye dominance. The Phase II HMD is planned to be VGA rather than NTSC in an effort to improve image quality.

AUDIO/VIDEO CODEC

The audio/video codec will be a single board, standards based codec that will accept analog audio and analog video (i.e., NTSC or VGA) and digitize and compress these inputs and multiplex the compressed data with an external data stream. The standards are: ITU H.261 based video, ITU G.722 based audio, and ITU H.221 based multiplexing. The base station A/V codec takes the base station PC display as the video source. The astronaut codec outputs the received and decompressed base station display video on the HMD. The codec interface to the communications system is planned to operate at 384 kbps; of this 384 kbps the audio will utilize 32 kbps and the digital bio-sensor data will utilize 8 kbps with the remainder allocated to compressed video. The quality of the video at these data rates is equivalent to video teleconferencing quality video. The codec will be unique to the WARP effort in that it will be an autonomous stand alone board (i.e., no PC required for operation) and be reduced to a size commensurate with the belt worn system.

BIOSENSOR

The serial data interface provides bandwidth for bio-sensor data. The WARP Phase I system will incorporate a commercially available Pulse Oximeter sensor. This sensor will allow the measurement of pulse rate and oxygen saturation of the blood. Data from the sensor will be transmitted to the base station, and displayed for the headset user or at the base station for observation by other astronauts. Phase II is planned to include an "on body" wireless human performance and fatigue monitoring system that permits candidate biosensors to communicate wirelessly with a belt-mounted transceiver/control module.

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